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(54) Title: ALKENYL AROMATIC POLYMER FOAMS AND PROCESSES FOR PREPARING SAME (57) Abstract Disclosed is an insulative, bimodal alkenyl aromatic polymer foam structure having microscopic pinholes in the cell walls to enhance the flexibility of the foam structure. Further disclosed is an insulative, bimodal alkenyl aromatic polymer foam structure containing carbon black. Further disclosed is a process for making low density alkenyl aromatic polymer foams prepared with a halogen-free blowing agent of carbon dioxide, lower alcohol and water. The cell size can be effectively controlled by controlling the amount of water in the blowing agent.		

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ALKENYL AROMATIC POLYMER FOAMS AND
PROCESSES FOR PREPARING SAME

5 The invention relates to a bimodal alkenyl aromatic polymer foam structure having enhanced flexural characteristics and/or enhanced thermally insulative properties. The present invention further relates to alkenyl aromatic polymer foam structures prepared using a halogen-free blowing agent comprising carbon dioxide, a C₁-C₆ alcohol, and water.

10 A bimodal foam structure is one with a bimodal cell size distribution of relatively larger primary cells and relatively smaller secondary cells. Most conventional foam structures have a unimodal cell size distribution only. A unimodal distribution has a
15 uniform or only primary cell size distribution. Various bimodal foam structures are disclosed in US-A-4,455,272 and US-A-4,559,367 and in EP-A0353701 (EPO Application No. 89114160.8).

20 US-A-4,559,367 relates a process for making a bimodal foam structure by incorporating finely-divided, water-containing organic vegetable matter into a polymer feedstock, melting the resulting solid mixture
25

, incorporating a volatile foaming agent into the solid mixture melt to form a foamable mixture, and extruding the foamable mixture through a die to form the foam structure.

5 US-A-4,455,272 relates a process for making a bimodal foam structure by injecting water and a physical blowing agent into a polymer melt and extruding the resulting mixture through a die to form the structure.

10 EP-A-0353701 relates a process for making a bimodal foam structure by incorporating into the polymer feedstock a fine, water-absorbing mineral powder, melting the resulting solid mixture, incorporating a
15 volatile foaming agent into the solid mixture melt to form a foamable mixture, and extruding the foamable mixture through a die to form the foam structure.

 Bimodal foam structures offer advantages over conventional unimodal foam structures. The advantages
20 include greater toughness and enhanced thermally insulating capability. Further, bimodal structures are typically made using water as a blowing agent component and unimodal structures typically are not. Since use of
25 water as a blowing agent component is desirable for environmental reasons, the manufacture of bimodal structures is similarly desirable.

 It would be desirable to further enhance the
30 thermally insulating capability of the bimodal foam structures. It would be further desirable to increase such insulating capability without detrimentally affecting the physical properties of the foam structure or detrimentally affecting its manufacture or processing.

A disadvantage of bimodal foam structures is their lack of flexibility. It would be desirable to have a bimodal foam structure which offers the enhanced toughness and thermally insulating capability of a bimodal foam structure yet offers enhanced flexibility.

For environmental reasons, it would be desirable to provide a low density alkenyl aromatic polymer foam structure with a halogen-free blowing agent of economical components. It would further be desirable to be able to control cell size of the foam with selection of type and amount of blowing agent.

According to a first aspect of the present invention, there is a flexible, alkenyl aromatic polymer foam structure comprising a foam of a thermoplastic polymeric composition of greater than 50 percent by weight of alkenyl aromatic polymer. The foam has relatively larger primary cells with an average cell size range of 0.05 to 1.2 millimeters and relatively smaller secondary cells ranging in average cell size from 5 percent to 50 percent of the average cell size of the primary cells. The primary and secondary cells constitute at least 90 percent of the total cell volume of the foam structure. The primary and secondary cells have pinholes between 1 and 30 percent by number of the total number of such cells. The presence of the pinholes enhances the flexibility of the foam structure versus a corresponding foam structure without pinholes.

Further to the first aspect of the present invention, there is a process for making the above-referenced foam structure, comprising: a) heating a thermoplastic polymer material comprising greater than 50 percent by weight alkenyl aromatic polymer to form a

melt polymer material, b) incorporating into the melt polymer material at an elevated pressure a blowing agent in liquid or gaseous form comprising at least 3 weight percent water based upon the total weight of the blowing agent to form a foamable gel and in an amount of at least 0.3 parts per hundred parts polymer material by weight, and c) expanding the foamable gel at reduced pressure to form the foam structure. Preferably, the foamable gel is expanded by extruding it through a die into a zone of lower pressure to form the foam structure.

According to a second aspect of the present invention, there is a thermally insulative, bimodal, alkenyl aromatic polymer foam structure comprising a) a foam of a thermoplastic polymer material of greater than 50 percent by weight of alkenyl aromatic polymer and b) an amount of carbon black sufficient to reduce the thermal conductivity of the foam below that of a corresponding foam without carbon black. The foam has a bimodal cell distribution of relatively larger primary cells with a cell size range of 0.05 to 1.2 millimeters and relatively smaller secondary cells ranging in cell size from 5 percent to 50 percent of the average cell size of the primary cells. The primary and secondary cells constitute at least 90 percent of the total cell volume within the foam structure. The addition of the carbon black results in a surprising and synergistic increase in thermally insulating capability or decrease in thermal conductivity greater than that observed when carbon black is added to a conventional unimodal foam structure of substantially only primary foam cells.

According to a third aspect of the present invention, there is a process for preparing a low

density, halogen-free, closed-cell foam comprising a plurality of closed cells having an average cell size of at least 0.1 millimeter. The term "low density" means foam densities of from 16 kg/m³ to 80 kg/m³. An alkenyl aromatic thermoplastic material is heated to form a polymer material melt. Into the melt is incorporated or mixed, preferably from 3 to 10 weight percent, based on the total weight of the polymer, of a halogen-free blowing agent mixture to form a foamable gel. The term "halogen-free foam structures" refers to low density foam structures formed by halogen-free or non-halogenated blowing agents. The blowing agent preferably contains from 15 to 95 weight percent of carbon dioxide, from 3 to 80 weight percent of a C₁-C₆ alcohol and from 0.4 to 45 weight percent of water, based on the total weight of the total blowing agent mixture. The foamable gel is expanded at a reduced or lower pressure to form the foam. It was found the cell size could be controlled by varying water content.

The foam structures comprise greater than 50 and more preferably greater than 70 percent by weight of an alkenyl aromatic polymer. The term alkenyl aromatic polymer is inclusive of polymers derived from one or more alkenyl aromatic compounds such as styrene, methylstyrene, ethylstyrenes, vinyl benzene, divinyl benzene, chlorostyrenes, and bromostyrenes. Minor amounts (that is, 5 percent by weight) of copolymerizable compounds such as C₁-C₄ methacrylates and acrylates, C₁₋₈ olefins, and C₄₋₈ dienes. Suitable compounds include acrylic acid, methacrylic acid, maleic acid, acrylonitrile, maleic anhydride, vinyl acetate, butadiene, pentadiene, hexadiene, ethylene, propylene, butylene, hexene, and octene.

The alkenyl aromatic polymer material may contain other thermoplastic materials as long as the alkenyl aromatic polymer comprises greater than 50 weight percent of alkenyl aromatic monomeric units. Suitable plastic materials may be selected from any
5 which can be blended with the alkenyl aromatic polymer and blown into a foam. Suitable plastics include polyolefins, polyvinylchloride, polystyrene, rubber-modified alkenyl aromatic polymers, cellulosic polymers,
10 polycarbonates, polyamides, polyesters, and polyvinylidene chloride. Suitable polyolefins include polyethylene, polypropylene and polybutylene. Preferred structures comprise substantially (that is, greater than 95 percent) and most preferably entirely of polystyrene,
15 because polystyrene foam is economical, and is commonly employed as a thermally insulating plastic foam.

The foam structures are generally formed by melting and mixing the alkenyl aromatic polymer itself
20 or with other polymers if present to form a plastic melt, incorporating a blowing agent into the plastic melt to form a foamable gel, and extruding the foamable gel through a die to form the foamed structure. During melting and mixing, the polymers are heated to a
25 temperature at or above the glass transition temperature and preferably above the melting point of the polymer. Melting and mixing of polymers and any additives is accomplished by any means known in the art such as with
30 an extruder, mixer, or blender. Likewise, the blowing agent, including water, is incorporated or blended into the plastic melt by any of the same above-described means. The blowing agent is blended with the plastic melt at an elevated pressure sufficient to prevent substantial expansion of the resulting plastic gel or

loss of generally homogeneous dispersion of the blowing agent within the gel. Unless otherwise specified, the blowing agent suitably is incorporated into the melt in a weight proportion of between 1 to 30 parts and preferably from 3 to 15 parts per hundred parts of the polymer to be expanded. The foamable gel is preferably passed through a cooler or cooling zone to lower the gel temperature to an optimum foaming temperature. For polystyrene, typical optimum foaming temperatures range from 110°C to 135°C. Melting, mixing, and cooling may occur in a single extruder, tandem extruders, or one or more extruders in series with separate mixers or coolers. The cooled gel is then passed through the die into a zone of reduced or lower pressure to form the foam structure. The zone of lower pressure is at a pressure lower than that in which the foamable gel is maintained prior to extrusion through the die. The lower pressure may be superatmospheric or subatmospheric (vacuum), but is preferably at an atmospheric level.

Unless otherwise specified, the blowing agents which may be utilized in combination with water include inorganic agents, volatile organic agents, and chemical agents which decompose into a gas or other byproducts. Suitable gaseous blowing agents include, but are not limited to nitrogen, carbon dioxide, air, and argon. Suitable volatile organic agents include halogenated and nonhalogenated aliphatic hydrocarbons. Suitable nonhalogenated aliphatic hydrocarbons include C₁₋₉ alkenes and alkanes such as n-butane, isobutane, n-pentane, ethane, propane, isopentane, n-hexane, and isohexane. Suitable halogenated aliphatic hydrocarbons include methyl chloride, ethyl chloride, perfluoromethane, chlorotrifluoromethane,

dichlorodifluoromethane, trichlorofluoromethane,
difluoromethane, perfluoroethane, 1-chloro-1,1-difluoro-
ethane, 1,1-difluoroethane, 1,1,1,2-tetrafluoro-ethane,
1,1,1-trifluoroethane, pentafluoroethane,
5 chlorotetrafluoroethane, 2-chloro-1,1,1,2-
tetrafluoroethane chloropentafluoroethane,
dichlorotetrafluoroethane, trichlorotrifluoroethane,
perfluoropropane, chlorheptafluoropropane,
dichloropropane, difluoropropane,
10 dichlorohexafluoropropane, perfluorobutane,
chlorononafluorobutane, and perfluorocyclobutane.
Suitable chemical blowing agents include
azodicarbonamide, azodiisobutyronitrile,
benzenesulfonhydrazide, 4,4-oxybenzene sulfonyl-
15 semicarbazide, p-toluene sulfonyl semicarbazide, barium
azodicarboxylate, N,N'-dimethyl-
N,N'dinitrosoterephthalamide, and trihydrazino triazine.

Preferred blowing agents are those using a
20 combination of water and an inorganic blowing agent such
as nitrogen, carbon dioxide, or argon. A most preferred
blowing agent comprises water and carbon dioxide.
Unless otherwise specified, the blowing agent preferably
comprises from 3 to 80 weight percent water and
25 preferably between 5 and 60 weight percent water based
upon the total weight of the blowing agent.

The present structure may contain additional
additives such as pigments, fillers, antioxidants,
30 extrusion aids, nucleating agents, stabilizing agents,
antistatic agents, fire retardants, and acid scavengers.

The foam component of the present structure preferably has density of 16 to 80 kilograms per cubic meter.

Bimodal foam structure are comprised of

5 relatively larger primary foam cells with an average cell size range of 0.05 to 1.2 millimeters and relatively smaller secondary foam cells ranging in cell size from 5 percent to 50 percent of the average cell size of the primary cells. Cell size is determined by

10 the optical microscopy method typically employed in the art in analyzing and characterizing bimodal foam structures. The relatively larger cells in the cell distribution are averaged to determine the average cell size of the primary cells, and the relatively smaller

15 cells in the cell distribution are averaged to determine the average cell size of the secondary cells. The secondary cells may be situated within the cell walls or struts of the primary cells, or may be situated outside

20 of or adjacent to the primary cells individually or in groups of two or more. A strut is a juncture of three or more cell walls. Preferably, the primary cells are generally dispersed throughout the secondary cells such that the foam of the present foam structure has a

25 generally heterogeneous dispersion of the two cell types throughout. Additional teachings directed to plastic foams with bimodal cell distributions are disclosed in US-A-4,455,272 and US-A-4,559,367 and in EP-A0353701.

30 Bimodal foam structures may be formed with "pinholes" between a portion of the foam cells. The pinholes are microscopic holes defined within cell walls between contiguous primary cells, contiguous secondary cells, or contiguous primary and secondary cells. The pinholes do not materially affect the closed-cell nature

of the foam as defined by ASTM D-2856 because the pinholes are present between only a relatively small proportion or portion of the foam cells. The pinholes are preferably present at between 1 and 30 percent by number and more preferably at between 5 and 20 percent by number of the total number of primary and secondary foam cells. Foam structures may be formed with or without pinholes.

Bimodal foams with pinholes exhibit a greater degree of flexibility than corresponding bimodal foams without pinholes. The greater flexibility results in a foam structure that is less brittle and easier to process and fabricate and handle during use without suffering breakage. Greater flexibility also provides greater resistance to cracking when used in stucco applications.

The primary and secondary cells of bimodal foam structures constitute at least 90 percent and preferably at least 95 percent of the total cell volume within the foam structure. Cells larger than the primary cells and smaller than the secondary cells should constitute only a relatively small proportion (less than 10 percent) of the volume displaced to ensure that the desired bimodal distribution of cell sizes will be present in the structure. Voids or cavities present in the foam structure not in the nature of a foam cell are not considered part of the total cell volume within the foam structure.

Though not bound by any particular theory, bimodal cell size distributions are believed to result when foamable gels contain a level of water exceeding the solubility of water in the polymer melt at the

extant processing conditions (for example, temperature, pressure, mechanical agitation, etc.). The excess water manifests itself in the form of secondary cells upon expansion of the foamable gel to a foam structure.

- 5 Use of aqueous blowing agent systems comprising
1 or more weight percent or more water by weight based
upon the total weight of the blowing agent typically
result in bimodal foam distributions in foam structures
made from commercially-available alkenyl aromatic
10 polymers, particularly polystyrene.

- The present foam structures are preferably at
least 90 percent closed-cell according to ASTM D-2856.
Such closed-cell foams are particularly efficacious in
15 thermally insulative applications.

- The blowing agent utilized to prepare bimodal
foam structures with pinholes comprises at least 3
weight percent water based upon the total weight of the
20 blowing agent. The water fraction of the blowing agent
must also comprise at least 0.3 parts per hundred by
weight based upon the weight of the alkenyl aromatic and
non-alkenyl aromatic polymers in the present structure.
25 The necessary water fractions refer to blowing agent
which is incorporated in liquid, or gaseous (including
vapor) form directly into the plastic or polymer melt by
external means such as injection into an extruder,
mixer, or blender and not by water-carrying or water-
30 generating solids incorporated into the plastic or
polymer melt as in the prior art. The use of proper
fractions of water in the blowing agent added to the
polymer melt externally in liquid or gaseous form and
proper selection of foaming temperature results in a
foam structure having the desired bimodal cell size

distribution with pinholes. The present invention does not preclude the incorporation of water-carrying or water-generating solids into the polymer melt, but water incorporated by means of such solids is not believed to be critical to pinhole formation; thus, water
5 incorporated by means of such solids is not considered in calculation of proper water fractions of blowing agents incorporated into the polymer melt in liquid or gaseous form. Proper selection of foaming temperature ensures a fine, homogeneous dispersion of water in the
10 foamable gel.

A bimodal foam structure containing carbon black is advantageous over a unimodal foam structure containing carbon black because the increase in
15 thermally insulating capability or decrease in thermal conductivity observed for a given level of carbon black is surprisingly greater. In other words, a bimodal foam structure with carbon black will show a greater increase
20 in thermally insulating capability or a greater decrease in thermal conductivity over a bimodal foam structure without carbon black than a unimodal foam structure with carbon black versus a unimodal foam structure without
25 carbon black. This disparity in increase in insulating capability or decrease in thermal conductivity upon addition of carbon black between bimodal and unimodal foam structures is surprising and unexpected. Further, a bimodal foam structure will exhibit a higher R-value
30 (thermally insulating capability) or lower thermal conductivity than a corresponding unimodal foam structure for a given level of carbon black. A corresponding foam structure is one substantially equivalent in average cell size according to ASTM D 3576-77 or optical microscopy in the primary cell size

range and substantially equivalent in foam density. The bimodal foam structure containing carbon black is advantageous over a unimodal foam structure containing same whether the bimodal structure is with or without pinholes.

5

The carbon black preferably comprises between 1.0 and 25 weight percent and more preferably between 2 and 10 weight percent of the foam structure based upon the weight of alkenyl aromatic or non-alkenyl aromatic polymers in the structure. The carbon black is preferably uniformly dispersed throughout the foam matrix of the present structure. The carbon black is further preferably distributed uniformly throughout the cell walls.

15

It was found surprising the cell size in halogen-free foam structures of the present invention could be effectively controlled by controlling the amount of water in the blowing agent mixture. Increasing amounts of water provided foams exhibiting larger average cell sizes. Thus, the cell size of the foams could be controlled by varying the water content of the blowing agent mixture.

20

25

A halogen-free foam structure is a foam structure formed with a non-halogenated blowing agent or a blowing agent free of halogen content such as chlorine or fluorine. Non-halogenated blowing agents include those free of the halogenated aliphatic hydrocarbons seen above. The present foam structure is not limited to those formed of non-halogenated blowing agents, but such blowing agents may be preferred for some applications.

30

Excellent skin quality and large cross-section can be obtained with the halogen-free foam structures when the cell size of the foam is small, i.e., less than 1.2 millimeters (mm).

5 Halogen-free foam structures of one embodiment having closed cells of a relatively small cell size are herein also referred to as "small cell foam". Foam structures of another embodiment having closed cells of a relatively large cell size may be referred to as
10 "large cell foam".

The term "small cell size" means cell sizes of from 0.1 to 1.2 mm. Advantageously, this small cell foam structure has at least from 97 to 99.9 percent,
15 preferably from 98.5 to 99.8 percent, of closed gas-containing cells therein.

A small cell halogen-free foam structure preferably has cells having an average cell size of from
20 0.1 to 1.1 mm and more preferably from 0.1 to 0.9 mm, is of a generally uniform cellular structure, and without discontinuities. In a preferred embodiment, the small cell foam structure has no substantial variation in
25 average cell size when cell size is measured by averaging cell diameter across the minimum cross-sectional dimension of the body (i.e., such as by ASTM Method D2842-69). The preferred embodiment further has a cross-sectional area of at least 8 in² (50 cm²), a
30 minimum cross-sectional dimension of at least 0.25 in (0.6 cm), and a density of from 1 to 5 pcf (16 kg/m³ to 80 kg/m³), preferably from 1.8-3.1 pcf (29 kg/m³ to 50 kg/m³).

The term "large cell size" means cell sizes of from greater than 1.2 to 3.0 mm. Advantageously, this large cell foam structure has at least from 97 to 99.9 percent, preferably from 98.5 to 99.8 percent, of closed gas-containing cells therein.

5

A large cell halogen-free foam structure preferably has cells having an average cell size of from 1.5 to 2.6 mm, and most preferably from 1.6 to 2.4 mm. In a preferred embodiment, the large cell foam structure has a cross-sectional area of at least 8 in² (50 cm²), a minimum cross-sectional dimension of at least 0.25 in (0.6 cm), and a density of from 1 to 5 pcf (16 kg/m³ to 80 kg/m³), preferably from 1.6-2.0 pcf (25.6 kg/m³ to 32 kg/m³).

15

To prepare a small cell halogen-free foam, carbon dioxide is generally employed in the proportions of from 15 to 95 weight percent, preferably from 30 to 90 weight percent, most preferably from 40 to 70 weight percent of total blowing agent. The lower alcohol is employed at a level of 3 to 80 weight percent and preferably at a level of 6 to 60 weight percent of the total weight of the total blowing agent mixture. Water is employed from 0.4 to 20 weight percent, preferably at a level of 0.4 to 10 weight percent, and most preferably from 0.4 to 3 weight percent of the total weight of the total blowing agent mixture.

20

To prepare a large cell halogen-free foam, carbon dioxide is preferably employed at a level of from 15 to 50 weight percent and more preferably from 26 to 43 weight percent. The lower alcohol is employed at a level of from 10 to 80 weight percent and more preferably from 22 to 53 weight percent. The water is

employed at a level of from 10 to 45 weight percent and more preferably from 21 to 35 weight percent. All weights are based upon the total weight of the blowing agent.

5 The blowing agent useful in this embodiment is a mixture of carbon dioxide, a lower alcohol and water. The term "lower alcohol" means any C₁-C₆ alcohol and preferably a C₁-C₄ alcohol. Lower alcohols include
10 methanol, ethanol, iso-propanol, propanol, butanol, pentanol, hexanol, and isomers thereof. Ethanol is highly preferred.

 For the halogen-free foam structure, the amount of water in the blowing agent mixture is based on
15 anhydrous alcohol ("dry alcohol"). If alcohol having less than 99.9 percent alcohol ("wet alcohol") is used, the amount of water contained in the alcohol should be subtracted from the defined proportions and, if
20 necessary, supplemented with additional water in order to satisfy the required amounts of water.

 Though the preferred process for making the various foam structures taught herein is an extrusion
25 process, it is understood that the structures may be formed by expansion of beads, which may be molded at the time of expansion to form structures of various shapes. Insulating panels formed from molded, expandable beads are commonly referred to as bead board.

30 The various foam structures may be used to insulate a surface by fashioning them in the form of panels and applying them to the surface. Such panels are useful in any conventional insulating applications

such as, for example, roofing, buildings, and refrigerators.

The various foam structures may be formed into a plurality of discrete foamed particles for
5 conventional loose-fill cushioning and packaging applications.

The following are examples of the present invention, and are not to be construed as limiting.
10 Unless otherwise indicated, all percentages, parts, or proportions are by weight.

EXAMPLES

15 Example 1

A bimodal foam structure having pinholes of the present invention was prepared and tested for its thermally insulating capability ("R" value) and
20 mechanical response in the compressive and flexural modes.

General purpose polystyrene resin of 200,000 molecular weight as determined by size exclusion
25 chromatography and other additives to control processing and cell nucleation were fed to a 2 1/2 inch (6.4 centimeter) extruder and intimately blended with a blowing agent mixture to form a foamable gel. The blowing agent was a mixture of 4 parts per hundred (pph)
30 carbon dioxide and 0.5 pph water based on resin weight. The gel was cooled to a foaming temperature of 127°C, and extruded through a die to form the polystyrene foam. The tables summarize measured foam physical properties and mechanical tests. R value was measured according to ASTM C518-85. Additive concentrations were 0.05 pph

talc, 0.05 pph calcium stearate, 0.05 magnesium oxide, 0.1 polyethylene, and 0.01 pph blue colorant based upon weight of the resin.

Compressive strength tests were carried out according to the methods of ASTM D 1621-79, and flexural tests were made according to ASTM C 20391. Measurements were made on an Instron 4204 Materials Testing System.

The cellular morphology of the foam structure was bimodal, a distribution of primary and secondary cells. Pinholes were present in cell walls of a portion of the primary cells.

The results of the mechanical tests demonstrated an enhanced degree of flexibility and toughness not typically exhibited in bimodal foam structures. This enhancement was due to the presence of pinholes in the cellular structure of the foam structure.

Table A
Foam Structure Physical Properties

Density (#/ft ³)	Cell Size (mm)	Open Cell (percent)	R-value/in measured (°F.ft ² .hr/ btu.in)
2.22	0.62	5.3	3.81

Table B
Mechanical Test Results for the Foam Structure

Test Direction	Compressive Mode				Flexural Mode		
	σ_Y (psi)	ϵ_Y (percent)	E_Y (psi)	T (in- #/in ³)	σ_P (psi)	ϵ_P (percent)	E_P (psi)
vertical	72.32	3.74	4171	8.55	-	-	-
extruded	46.52	3.91	2086	5.57	105.3	10.12	3283
horizontal	23.50	3.46	1008	3.04	-	-	-

σ_Y is the stress at yield.

ϵ_Y is the strain at yield.

E_Y is the compressive mode modulus.

T is the foam toughness up to the break point.

σ_P is the stress at the peak of the flexural stress-strain curve.

ϵ_P is the strain at the peak stress.

E_P is the flexural mode modulus.

In Examples 2-3, bimodal foam structures with carbon black of the present invention were prepared.

Example 2

Foam structures were made with an apparatus comprising a 2-1/2 inch (6.4 centimeter) extruder, a mixer, a cooler, and a die in series. Polystyrene resin having a molecular weight of 200,000 as measured by size exclusion chromatography was fed to the extruder along with 10 percent carbon black, 0.05 pph magnesium oxide, 0.05 pph calcium stearate, and 1.0 pph hexabromocyclododecane by weight to form a polymer melt. A mixture of 1.5 pph water and 4 pph carbon dioxide was added to the polymer melt in the mixer to form a foamable gel. The foamable gel was cooled to 125°C and

extruded through the die and expanded between substantially parallel forming plates. The die pressure was 1100 psig (7.6 MPa). The foam structure had primary cells of 0.2 millimeter (mm) in size and a density of 2.3 pcf (36 kg/m³). The foam had a bimodal cell structure with secondary cells in struts and cell walls wherein the secondary cells were one-fifth the size of the primary cell size. Further, the foam structure had pinholes between foam cells and the interior of the foam. Pinholes were present at between 1 percent and 30 percent of the cells. The K-factor or thermal conductivity of the foam at 180 days of aging was 0.202 Btu-in/F°-ft²-hr (0.0291 W/(m.K)).

15 Example 3

Using the apparatus and process of Example 2, 7 percent by weight carbon black, 0.05 parts per hundred calcium stearate, 0.05 parts per hundred magnesium oxide, and 0.2 parts per hundred linear low density polyethylene per hundred parts polystyrene resin (density = 0.915-0.93 grams/cubic centimeter; melt index 2.0-2.5) were blended in the extruder to form a polymer melt. A blowing agent mixture of 0.5 parts per hundred water and 4 parts per hundred carbon dioxide were added to the polymer melt to form a foamable gel. The foamable gel was cooled to 128°C, and expanded through a die to atmospheric pressure between parallel forming plates. The die pressure was 1200 psig (8.3 MPa). The foam structure had a bimodal cell distribution with an average primary cell size of 0.22 mm. The foam structure had internally connected pinholes between cells, and had secondary cells in the struts and cell walls. Pinholes were present at between 1 percent and 30 percent of the cells. Foam structure density was 3.2

pcf (51 kg/m³) (with skins). The K-factor (Btu-in/F°-ft²-hr) after 3 days of aging was 0.212 (0.0306 W/(m.K)), which corresponded to R/inch of 4.7 (32 (m.K)/W; R/cm = 13 (m.K)/W).

5 Examples 6-11

Small cell foam structures were prepared according to the process of the present invention, utilizing a 2 inch (6.1 centimeters) diameter extruder
10 which feeds a rotary mixer. The rotary mixer discharge was passed through three heat exchangers. The discharge from the heat exchangers was in turn passed through a plurality of interfacial surface generators or static mixers. The discharge from the static mixers was passed
15 to a slot die. Foam was discharged from the slot die at a rate of 60 kg/hr (130 pounds per hour). Small cell foams with varying amounts of water in the blowing agent mixture were prepared in accordance with the present
20 invention. The compositions of each foam sample and the respective blowing agent proportions are set forth in Table C. The results of the small cell foam evaluation are given in Table D below.

25 Comparative Examples 6-9

Foam samples (Comparative Examples 6-9) were prepared following the procedure of Examples 6-11, except that water was omitted from the blowing agent.
30 The other components of the blowing agent mixture are indicated in Table C below. The results of the foam evaluation are given in Table D below.

Table C - SMALL CELL FOAMS

Example / Polymer Composition	PS1, parts	Nucleating Agent ² , pph ⁴	Blowing Agents, (weight percent)		
			CO ₂	EtOH ³	H ₂ O
Ex. 8	100	---	90.9	8.65	0.45
Ex. 9	100	---	66.7	31.6	1.7
Ex. 10	100	0.15	41.7	55.3	3.0
Ex. 11	100	0.15	46.1	51.1	2.8
Ex. 12	100	0.15	44.4	52.8	2.8
Ex. 13	100	0.15	46.4	50.8	2.8
Comp. Ex. 8*	100	---	100	---	---
Comp. Ex. 9*	100	0.15	41.7	58.3	---
Comp. Ex. 10*	100	0.10	46.1	53.9	---
Comp. Ex. 11*	100	0.15	42.8	57.2	---

* Not an example of the present invention

1 PS is a polystyrene resin having a molecular of approximately 200,000.

2 The nucleating agent is talc

3 EtOH is ethanol of 99.9 percent purity

4 pph is parts per hundred, based on the total weight of the polymer

Table D - SMALL CELL FOAM PROPERTIES

Example / Properties	Fresh Foam Properties		Cured Foam Properties								Skin Quality / Surface Appearance ⁶
	Density (kg/m ³)	Cell Size (mm) V	Density (kg/m ³)	Cell Size ¹ (mm)			Compressive Strength ² (kg/m ³)				
				V3	E4	H5	V	E	H		
Ex. 8	41.2	0.31	40.7	0.31	0.17	0.29	525	210	251	Good	
Ex. 9	34.1	0.42	33.2	0.37	0.34	0.40	389	218	213	Good	
Ex. 10	36.2	0.33	35.9	0.33	0.24	0.35	399	225	237	Excellent	
Ex. 11	37.6	0.35	37.3	0.40	0.35	0.43	450	253	264	Good	
Ex. 12	34.5	0.34	34.0	0.45	0.33	0.56	350	146	236	Excellent	
Ex. 13	33.9	0.37	33.7	0.47	0.35	0.47	372	207	244	Excellent	
Comp. Ex. 8*	44.5	0.20	43.6	0.18	0.18	0.16	431	527	272	Poor	
Comp. Ex. 9*	40.7	0.32	40.4	0.40	0.33	0.49	290	397	413	Good	
Comp. Ex. 10*	42.8	0.36	42.5	0.43	0.34	0.47	416	431	416	Fair	
Comp. Ex. 11*	37.2	0.33	37.1	0.35	0.26	0.39	555	204	213	Fair	

* Not an example of the present invention

² Compressive strength as measured by ASTM 1621⁴ E is in extrusion direction⁶ Skin Quality/Surface Appearance is visual evaluation based on the following criteria:

Excellent = Very smooth surface and no pinholes/spots

Good = Smooth surface and/or very small pinholes/spots

Fair = Reasonably smooth surface and/or small pinholes/spots

Poor = Rough surface and/or pinholes/spots

¹ Cell size as measured by ASTM D3576-77³ V is in vertical direction⁵ H is in horizontal direction

As readily apparent from the data shown in Table D, the small cell foams of the present invention prepared using a blowing agent mixture of CO₂, ethanol and water exhibit improved skin quality and surface appearance. Further, a comparison of the foam prepared in Example 8 with the foam prepared in Comparative Example 7, both prepared with the same amount of carbon dioxide in the blowing agent mixture, clearly shows that by incorporating water in the blowing agent mixture (Example 8) the foam not only exhibits an improved skin quality, but also has a lower density than the foam prepared without the presence of water (Comparative Example 7).

Examples 12 and 13

Large cell alkenyl aromatic polymer foam structures were prepared with varying amounts of water in the blowing agent mixture in accordance with the present invention using the same procedure and type of equipment as described in Examples 6-11. The large cell foam was discharged from the slot die at a rate of 200 pounds per hour (91 kg/h). The compositions of each foam sample and the respective blowing agent proportions are set forth in Table E. The results of the large cell foam evaluation are given in Table F below.

Comparative Examples 12 and 13

Foam structures 12 and 13 were prepared following the procedure of Examples 12 and 13 except the alcohol or water component was omitted. The other components of the blowing agent mixture are indicated in Table E below. The results of the foam evaluation are given in Table F below.

Table E - LARGE CELL FOAMS

Example / Polymer Composition	PS ¹ , parts	Nucleating Agent ² , pph ⁴	Blowing Agents, (weight percent)		
			CO ₂	EtOH ³	H ₂ O
Ex. 14	100	0.05	26	53	21
Ex. 15	100	0.05	43	22	35
Comp. Ex. 14*	100	0.05	56	---	44
Comp. Ex. 15*	100	0.05	33	67	---

* Not an example of the present invention

1 PS is a polystyrene resin having a molecular of approximately 200,000.

2 The nucleating agent is calcium stearate

3 EtOH is ethanol of 99.9 percent purity

4 pph = parts per hundred

Table F - LARGE CELL FOAM PROPERTIES

Example / Properties	Fresh Foam Density (kg/m ³)	Cured Foam Properties	
		Average Cell Size (mm)	Open cells (percent)
Ex. 14	30.6	2.5	0
Ex. 15	30.6	2.4	0
Comp. Ex. 14*	30.8	1.4	0
Comp. Ex. 15*	30.9	1.3	0

* Not an example of the present invention

The data in Table F shows that the cell size of foams prepared using a blowing agent mixture according to the present invention (Examples 12 and 13) can be increased by 70 percent or more compared to the foams prepared in Comparative Examples 12 and 13 where either ethanol or water was omitted from the blowing agent mixture.

While embodiments of the foam structures of the present invention and processes for making have been shown with regard to specific details, it will be appreciated that depending upon the manufacturing process and desired physical properties, the present invention may be modified by various changes while still being fairly within the scope of the novel teachings and principles herein set forth.

CLAIMS:

1. A process for making a closed-cell alkenyl aromatic polymer foam structure comprising:

a) heating a thermoplastic polymer material comprising greater than 50 percent by weight of alkenyl aromatic polymer to form a melt polymer material;

5 b) incorporating into the melt polymer material at an elevated pressure a blowing agent to form a foamable gel;

c) cooling the foamable gel to a selected foaming temperature; and

10 d) expanding the foamable gel at a reduced pressure to form the foam structure, wherein the blowing agent contains water

2. A process according to Claim 1, wherein at least one of the following requirements apply:

(i) the blowing agent is incorporated in a liquid or gaseous form and the comprises water in an amount of at least 3 weight percent based upon the total weight of the blowing agent and at least 0.3 parts per hundred parts of polymer material by weight;

20 (ii) the foamable gel contains an amount of carbon black sufficient to reduce the thermal conductivity of the foam structure; and

25

(iii) the blowing agent contains carbon dioxide, a C₁₋₆ alcohol, and water.

5 3. A closed-cell alkenyl aromatic polymer foam structure, comprising a foam of a thermoplastic polymeric composition of greater than 50 percent by weight of an alkenyl aromatic polymer, said foam having relatively larger primary cells with an average cell size range of 0.05 to 1.2 millimeters and relatively smaller secondary cells ranging in cell size from 5 percent to 50 percent of the average cell size of the primary cells, the primary and secondary cells constituting at least 90 percent of the total cell volume of the foam structure, and at least one of (i) pinholes between 1 and 30 percent by number of the total number of primary and secondary cells and (ii) an amount of carbon black sufficient to reduce the thermal conductivity of the foam below that of a corresponding foam without carbon black.

20 4. A flexible, closed-cell alkenyl aromatic polymer foam structure, comprising a foam of a thermoplastic polymeric composition of greater than 50 percent by weight of an alkenyl aromatic polymer, the foam having relatively larger primary cells with an average cell size range of 0.05 to 1.2 millimeters and relatively smaller secondary cells ranging in cell size from 5 percent to 50 percent of the average cell size of the primary cells, the primary and secondary cells constituting at least 90 percent of the total cell volume of the foam structure, the primary and secondary cells having pinholes between 1 and 30 percent by number of the total number of primary and secondary cells.

5. A process for making a closed-cell alkenyl aromatic polymer foam structure comprising a foam having relatively larger primary cells with an average cell size range of 0.05 to 1.2 millimeters and relatively smaller secondary cells ranging in cell size from 5 percent to 50 percent of the average cell size of the primary cells, the primary and secondary cells constituting at least 90 percent of the total volume of the foam structure, the primary and secondary cells having pinholes between 1 and 30 percent by number of the total number of primary and secondary cells, said process comprising:

- a) heating a thermoplastic polymer material comprising greater than 50 percent by weight of alkenyl aromatic polymer to form a melt polymer material;
- b) incorporating into the melt polymer material at an elevated pressure a blowing agent to form a foamable gel;
- c) cooling the foamable gel to a selected foaming temperature; and
- d) expanding the foamable gel at a reduced pressure to form the foam structure, the process being characterized in that the blowing agent is incorporated in a liquid or gaseous form and comprises water in an amount of at least 3 weight percent water based upon the total weight of the blowing agent and at least 0.3 parts per hundred parts of polymer material by weight.

6. A thermally insulative, closed-cell alkenyl aromatic polymer foam structure comprising a foam of a thermoplastic polymer material of greater than 50 percent by weight of alkenyl aromatic polymer, the foam having relatively larger primary cells with a cell size range of 0.05 to 1.2 millimeters and relatively smaller

secondary cells ranging in cell size from 5 percent to 50 percent of the average cell size of the primary cells, the primary and secondary cells constituting at least 90 percent of the total cell volume within the foam structure, the foam structure being characterized in that the foam has an amount of carbon black
5 sufficient to reduce the thermal conductivity of the foam below that of a corresponding foam without carbon black.

10 7. A process for preparing a closed cell, alkenyl aromatic polymer foam having an average cell size of at least 0.1 millimeter, comprising:
a) heating an alkenyl aromatic polymer material to form a polymer material melt;
15 b) incorporating into the polymer material melt at an elevated pressure a halogen-free blowing to form a foamable gel; and
c) expanding the foamable gel at a lower
20 pressure to form a foam structure, the process being characterized in that the blowing agent contains carbon dioxide, a C₁₋₆ alcohol, and water.

25 8. A process according to any one of Claims 1, 2, 5, 6, and 7, wherein the alkenyl aromatic polymer contains less than 5 percent by weight of at least one copolymerizable monomers.

30 9. A process according to any one of Claims 1, 2, 5, and 6 to 8, wherein the polymer material comprises greater than 70 percent by weight of an alkenyl aromatic polymer.

10. A process according to Claim 9, wherein the polymer material comprises greater than 95 percent of alkenyl aromatic polymer.

5 11. A process according to Claim 10, wherein the polymer material consists entirely of alkenyl aromatic polymer.

10 12. A process according to any one of Claims 1, 2, 5, and 6 to 11, wherein the alkenyl aromatic polymer is polystyrene.

15 13. A process according to any one of Claims 1, 2, 5, and 6 to 12, wherein the blowing agent is incorporated into the polymer material melt in a weight proportion of from 3 to 15 parts per hundred parts of the polymer melt.

20 14. A process according to any one of Claims 1, 2, 5, and 8 to 13, wherein the blowing agent comprises water and carbon dioxide.

25 15. A process according to any one of Claims 1, 2, 5, and 7 to 14, wherein the blowing agent comprises between 5 and 60 weight percent water based upon the total weight of the blowing agent.

16. A process according to Claim 6, wherein the carbon dioxide is used in an amount of 0.5 to 6 weight percent by weight of the polymer melt.

30 17. A process according to Claim 7, wherein the blowing agent is from 3 to 10 weight percent, based on the total weight of the polymer, of a halogen-free blowing agent mixture of from 15 to 95 weight percent of carbon dioxide, from 3 to 80 weight percent of a C₁₋₆

alcohol and from 0.4 to 45 weight percent of water, based on the total weight of the blowing agent.

18. A process according to Claim 7 or Claim 17, wherein the foam has a cell size from 0.1 to 0.9 millimeters and the blowing agent mixture is from 40 to 70 weight percent of carbon dioxide, from 6 to 60 weight percent of a C₁₋₆ alcohol and from 0.4 to 3 weight percent of water, based on the total weight of the polymer.

19. A process according to Claim 7 or Claim 17, wherein the foam has a cell size from greater than 1.2 to 3.0 millimeters and the blowing agent mixture is from 15 to 50 weight percent of carbon dioxide, from 10 to 80 weight percent of a C₁₋₆ alcohol and from 10 to 45 weight percent of water, based on the total weight of the polymer.

20. A process according to any one of Claims 7 and 17 to 19, wherein the C₁₋₆ alcohol is ethanol.

21. A foam structure according to any one of Claims 3, 4 and 6, wherein the alkenyl aromatic polymer contains less than 5 percent by weight of at least one copolymerizable monomers.

22. A foam structure according to any one of Claims 3, 4, 6 and 21, wherein the polymer material comprises greater than 70 percent by weight of an alkenyl aromatic polymer.

23. A foam structure according to Claim 22, wherein the polymer material comprises greater than 95 percent of alkenyl aromatic polymer.

24. A foam structure according to Claim 23, wherein the polymer material consists entirely of alkenyl aromatic polymer.

5 25. A foam structure according to any one of Claims 3, 4, 6, and 21 to 24, wherein the alkenyl aromatic polymer is polystyrene.

10 26. A foam structure according to any one of Claims 3, 4, 6, and 21 to 25, wherein the foam structure has a generally heterogeneous dispersion of the two cell types throughout.

15 27. A foam structure according to any one of Claims 3, 6, and 21 to 26, wherein the primary and secondary cells have pinholes between 1 and 30 percent by number of the total number of primary and secondary cells.

20 28. A foam structure according to Claim 4 or Claim 27, wherein said pinholes are present between 5 and 20 percent by number of the total number of primary and secondary foam cells.

25 29. A foam structure according to any one of Claims 3, 4, 6, and 21 to 28, wherein carbon black is present in an amount from 1.0 to 25 weight percent based upon the weight of the polymer material.

30 30. A foam structure according to Claim 29, wherein the carbon black comprises between 2 and 10 weight percent based upon the weight of polymer material.

31. A foam structure produced by a process of any one of Claims 1, 2, 5, and 6 to 20.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US93/05435

A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) : C08J 9/12, 9/14

US CL : 106/122; 264/53; 521/79, 81, 138, 142, 143, 145, 146, 180, 182

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 106/122; 264/53, DIG 5, DIG 13; 521/79, 81, 138, 142, 143, 145, 146, 180, 182

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US, A, 4,559,367 (HURPS et al) 17 DECEMBER 1985 Entire document.	1-7 & 16-19
A	US, A, 4,801,484 (YAO et al) 31 JANUARY 1989 Entire document.	1-7 & 16-19
A	US, A, 4,795,763 (GLUCK et al) 03 JANUARY 1989 Entire document.	1-7 & 16-19

☐ Further documents are listed in the continuation of Box C.
 ☐ See patent family annex.

* Special categories of cited documents:	T	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
A document defining the general state of the art which is not considered to be part of particular relevance	X	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
E earlier document published on or after the international filing date	Y	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
L document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	g	document member of the same patent family
O document referring to an oral disclosure, use, exhibition or other means		
P document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search

29 JULY 1993

Date of mailing of the international search report

20 SEP 1993

Name and mailing address of the ISA/US
Commissioner of Patents and Trademarks
Box PCT
Washington, D.C. 20231

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US93/05435

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☒ Claims Nos.: 8-15 & 20-31
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest.
☐ No protest accompanied the payment of additional search fees.